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EFFECTS ON HUMAN PERFORMANCE OF COMBINED ENVIRONMENTAL STRESS

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13. ABSTRACT

Research studies of environmental effects normally expose subjects to only one stress at a time, while in operational flying there are usually several stresses acting simultaneously. The possibility exists that effects of such combined stresses may be greater than would be predicted from single stress studies. There have been relatively few laboratory studies of human performance in which the subjects have been exposed to such combined stresses. This paper presents a critical review of these past studies from the particular viewpoint of whether performance decrements from combined stresses are more severe than would be predicted from single stress studies. Although the number of past studies is not sufficient to present a consistent or conclusive picture, they do suggest that combinations of environmental stresses do not present a special hazard in flying that could not be anticipated from results of single stress studies.

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FOREWORD

This report supports research being performed by the Aerospace Medical Research Laboratory. The information was also presented in September 1970 at the Aerospace Medical Panel of the Advisory Group for Aeronautical Research and Development, NATO, held in Garmisch-Partenkirchen, Germany.

This technical report has been reviewed and is approved.

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EFFECTS ON HUMAN PERFORMANCE OF COMBINED ENVIRONMENTAL STRESSES

INTRODUCTION

There has been much laboratory study of flight environmental stresses and their effects on safety and flying ability of aircrew personnel. Almost all such research, however, has been confined to single stress studies, in which only one condition at a time was allowed to deviate from the normal earth environment. Little attention has been given to the possible interactive effects of combined stresses.

In flight there is normally simultaneous exposure to several environmental stresses, involving combinations of noise, heat or cold, reduced cabin pressure, acceleration and vibration. In addition, the person may at the same time suffer impairment from fear, drugs, lack of sleep, or other internally derived stresses. An important question arises, therefore, as to whether the possible hazards and performance impairments from several stressors acting together, as they occur in flight, can be predicted adequately from research on stresses studied singly. It seems possible that stressors acting in combination might produce impairments that are considerably greater than would be expected from the findings of single stress experiments.

This review examines the applicable research literature to see how human performance is affected when persons are exposed simultaneously to two or more stresses. The primary interest in this review is in combinations of stressors that are external and imposed on the individual by environmental extremes (e.g., altitude, temperature and noise). Also included in the review, however, are combinations of such external stressors with other stresses internal to the individual (e.g., alcohol, drugs and sleep loss).

DIFFICULTIES IN CONDUCTING COMBINED STRESS STUDIES

Although interest in the possible effects of combined environmental stresses on performance has been building up in about the past 10 years, there have been relatively few experimental studies in this area. There are several likely reasons to account for this dearth of combined stress experiments. First, most environmental facilities are designed to control only one environmental variable, and thus cannot provide combined stress conditions unless especially modified to do so. Another serious constraint is the increased complexity added to the experimental design when more than one stress is included. To make such an experiment most valuable it is desirable to test all possible combinations of the stresses being studied. But the number of such combinations can easily become unmanageable. The general equation for computing the number of such combinations is

$$\text{Combinations} = N^S$$

Where N is the number of levels of each stressor, and S is the number of stressors being combined.

If, for example, an experiment were to include two stressors, and three levels for each (e.g., control, medium and maximum), the number of possible combinations would be nine. Such a number of replications of the basic experiment would be sufficient to discourage many investigators. But consider the dilemma if the number of stressors is increased to three, thereby increasing the number of possible combinations to 27.

THEORETICAL EFFECTS OF STRESS COMBINATIONS

Before reviewing the existing data it would seem helpful to consider the possible effects on performance that might be expected when stresses are combined. Broadbent (1) discussed the possible interactions of effects on performance when different environmental stresses are combined. Both the performance and physiological effects of combined stress interactions have been reviewed by Murray and McCally (2). The possible effects may be grouped into four major categories.

1. *No effect.* Combinations produce no effects greater than those of any of the included stressors singly.
2. *Additive effect.* Combinations produce effects greater than any single stressors, but not greater than addition of effects from single stressors.
3. *Greater than additive effect.* Combinations produce effects greater than mere addition of single stress effects. This possible result is sometimes referred to as "synergistic."
4. *Subtractive effect.* Combinations produce effects lower than effects produced by single stressors. This result may be referred to as "antagonistic."

All of these four types of outcomes seem to be likely on a theoretical basis, depending on the nature of the effects of individual stressors, and the possible interactions among them. Outcome number 1 seems most likely when the stressors included in the combination are unequal in their effects. Then the more severe stress would dominate the results, and variables with less effect would make no detectable addition to the overall result.

Outcome number 2 seems to be the most likely when the stressors are more or less equal in their effects, and their mechanisms of action are independent. That is, the mechanisms whereby they cause impairment of performance are basically different, and no synergistic or antagonistic effects can be anticipated.

The outcomes of greatest scientific interest are probably numbers 3 and 4, where either synergistic or antagonistic mechanisms would be indicated by the results. These are also the types of stress interactions of greatest practical or operational interest. An antagonistic interaction between stressors could be used to counteract undesirable stress effects or to increase human stress tolerance. On the other hand, stress combinations producing synergistic effects could represent unusual hazards that are not apparent from results of single stress studies.

In this review certain restrictions were observed in selecting the experimental studies to be covered. Since my concern was with human performance all studies of animals were excluded. Also excluded were purely physiological studies, whether human or animal. Since my primary interest was in environmental stressors the literature search was concentrated on studies involving two or more externally imposed stresses. Also included, however, were studies in which an environmental stressor was combined with one or more internal or host stresses.

The search for studies meeting these particular criteria was rather difficult and tedious, and undoubtedly some relevant literature was missed. The number of studies meeting the selection criteria turned out to be rather limited. Particularly limited was the number of studies using combinations of environmental stresses, as opposed to combinations of environmental and host stresses. Of the relevant studies uncovered, a disappointingly large proportion yielded results that were negative, indeterminate, or inconsistent. This suggests that this is either an unprofitable field for research, or a large field that is still essentially untapped. In the review which follows the studies have been separated into two groups: (1) combinations of environmental stressors; and (2) combinations of environmental and internal, or host, stressors.

COMBINATIONS OF ENVIRONMENTAL STRESSORS

As already mentioned, there appear to have been relatively few studies of human performance involving simultaneous exposures to two or more environmental stressors. These few studies are limited, essentially, to various combinations of noise, vibration, heat and acceleration. Table 1 provides a summary of these studies and some indications of their findings with regard to the effects of combined stress.

TABLE 1
Summary of Research Findings for Combinations of Two or More Environmental Stressors

Stressors	*Authors*	*Stress Conditions*	*Performance Measures*	*Interaction Category**	*Remarks*
Noise & Heat	Viteles & Smith (3)	Noise up to 90 dB; Heat up to Eff. Temp. of 87°F: 4 hr. exposures.	Mental Multiplication, Number Checking, Code, Locations, Pursuit, Lathe, & Discrimeter	1 & 2	Most tests showed no consistent decrements. Slight additive effect for Lathe test.
	Dean, McGlothlen & Monroe (4)	Noise up to 110 dB; Heat up to Eff. Temp. of 92.8°F; 20 min. exposures.	2-D Comp. Tracking; Visual Monitoring	—	No significant decrements in performance.
Noise & Vibration	Dean, McGlothlen & Monroe (7)	Noise up to 114 dB; Random vibration up to .325 RMS G.	2-D Comp. Tracking; Visual Monitoring; Visual Acuity	—	Study designed to detect deterioration from repetitive exposures. No such deterioration found.
	Harris & Shoenberger (8)	Noise up to 110 dB; Vibration, sinusoidal z axis, at 5 Hz up to 0.25 G; 20 min. exposures.	2-D Comp. Tracking; Choice Reaction Time	1 & 2	Additive effect only for vertical component tracking.
	Sommer & Harris (9)	Noise up to 110 dB; Vibration, z axis, at 5 Hz, up to 0.25 G; 20 min. exposures; Testing at 6 AM and 3 PM.	Mental Arithmetic	—	No comparison of single vs combined stress. No general effect of time of day.
Vibration & Acceleration	Clarke et al. (10)	Vibration, x axis, 11 Hz, up to 3.0 G; accel., x axis, at 3.85 G.	Dial Reading	—	Decrement in dial reading with increase in vibration. Data only for 3.85 G acceleration.
	Dolkas & Stewart (12)	Vibration, x axis, 11 Hz, up to 3.0 G; acceleration, x axis, up to 3.5 G.	2-D Comp. Tracking	2	Severe decrement in tracking at maximum vibration and acceleration combination. Results for only 2 subjects.
Heat, Glare & Distracting Noise	Pepler (13)	Heat up to 100°F (dry bulb), 90°F (wet bulb), visual glare and quiet speech	1-D Pursuit Tracking	2	Both heat and glare caused decrement in performance. Greatest decrement for combination of heat and glare.

*For explanation of categories see text.

Antedating the current interest in aerospace environment, a study by Viteles and Smith (3), combining heat and noise, was stimulated by an interest in the requirements that should be met by air conditioning systems. This was a complex and ambitious study, involving six subjects, 6 days a week, for 7 weeks. Each environmental exposure was of 4 hours duration. The noise was broadband, at levels of 72, 80 and 90 dB. Temperature levels were 73, 80 and 87°F effective temperature. A still higher temperature of 94°F effective temperature was also tried, but no subjects were able to tolerate this temperature and complete a 4 hour exposure. Tests were run at all 9 combinations of the three levels of heat and noise. Viteles and Smith used a battery of 7 performance tests, as listed in Table 1. Each test could be scored in terms of performance output, and this expressed in percent of the output for the maximum output condition. For four of the seven tests the maximum output occurred at the maximum noise (90 dB) condition, suggesting that for these tests noise benefited rather than impaired performance. In most, but not all instances, poorest performance occurred at the maximum heat (Eff. Temp. 87°F) condition. Only for one, the Lathe Test, did there seem to be any indication of an additive effect for the combination of heat and noise. The results for this test are plotted in Figure 1.

Another study combining heat and noise, by Dean, McGlothlen and Monroe (4), used somewhat higher exposure levels than Viteles and Smith (3). The levels were 70 and 110 dB (broadband) for noise, and ranged from 63 to 93°F effective temperature for heat. But the exposure duration was rather short, 20 minutes. Using 10 pilots as subjects, they found no significant performance decrements on a 2-dimensional tracking test and

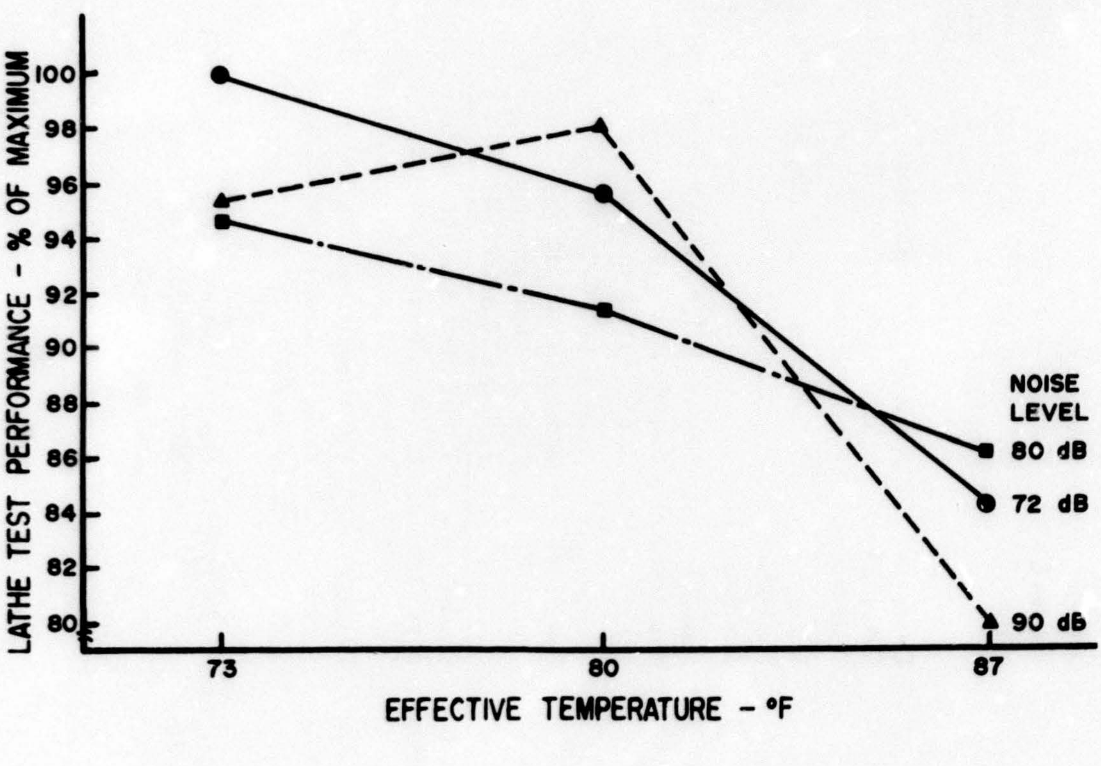

Figure 1. Effect of combined heat and noise on performance on a lathe test [data from Viteles and Smith (3)]

on two different visual monitoring tasks during exposures to combined noise and heat stress, or to either stress alone. The lack of performance decrements during exposure to noise is not unusual [see review by Grether (5)]. Also, for the heat level used, the duration of the exposure was apparently insufficient to cause a decrement (see review by Wing (6)).

A combination of noise and vibration stress, in relation to performance, was studied by Dean, McGlothlen and Monroe (7). Their primary interest, however, was not on the effects of combined stress, but rather on the effects of repeated exposure to the noise and vibration that aircrews would experience in a certain helicopter. Their experiment found no detrimental effect on performance from repeated exposures. More recently Harris and Shoenberger (8) studied the effect of combined noise and vibration on a 2-dimensional compensatory tracking task and a choice reaction time task. They used broadband noise at 85 and 110 dB. Vibration was either zero or vertical vibration at 5 Hz and 0.25 peak G. Their major findings for tracking are shown in Figure 2. For the vertical component of tracking there is evidence of a rather clear additive effect from the combined effects of noise and vibration. For the horizontal component of tracking, as shown in Figure 2, and for reaction time, there was a significant decrement caused by vibration, but not by the noise. Thus there was no additive effect from the combination.

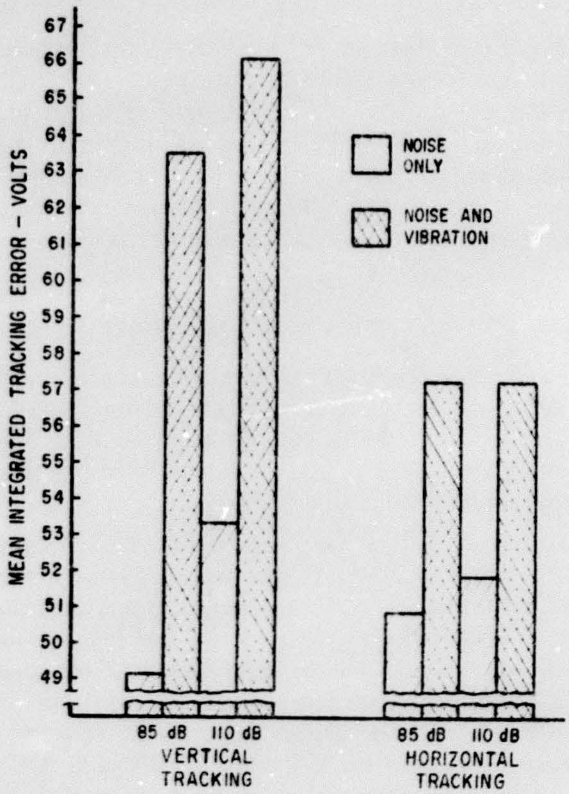

Figure 2. Effect of combined noise and vibration (5 Hz, 0.25 G) on tracking error [data from Harris and Shoenberger (8)]

An additional study by Sommer and Harris (9) also used 80 and 110 dB noise and vertical vibration at 5 Hz and 0.25 G. Their measure of performance was a mental arithmetic task requiring memory of a 6 digit number, and then subtraction of a 4 digit number from this. The primary focus of the study was on a possible time of day effect on performance. Their study found no general or consistent decrement from the noise and vibration combination.

There have been two studies of performance using vibration superimposed on linear acceleration on a centrifuge. One of these studies by Clarke et al. (10) exposed subjects to x axis linear acceleration at +3.85 G, such as an astronaut would experience during a rocket launch. The superimposed vibration was also in the x axis, at 11 Hz, and ranged from 0.4 to 3.0 G. Dial reading ability, as would be predicted from other studies (see review by Grether (11)) showed a progressive decline with increased vibration. Since only one level of linear G was used, the effects of combining the two stresses could not be determined.

A similar combination of vibration and acceleration was also studied by Dolkas and Stewart (12), using a 2-dimensional compensatory tracking test. They also used x axis vibration, at 11 Hz, up to 3.0 G. Linear acceleration was also in the +x direction, at 2 and 3.5 G. In this study both the vibration and acceleration caused impairment of tracking ability, and the greatest decrement occurred at the most severe combination of the two stresses, suggesting an additive effect. However, most of the data were obtained on only two pilot subjects, and only a limited number of the possible combinations were run.

A somewhat unusual combination of heat with other stresses was studied by Pepler (13). In one experiment a high temperature of 100°F (dry bulb) and 90°F (wet bulb) was combined with visual glare from a bright light in the field of view. In a second experiment the same temperature condition was combined with the distraction produced by quiet but interesting speech. In both experiments performance was measured with a 1-dimensional pursuit tracking test. In both experiments the performance degradation caused by heat was increased by the single added stress (either visual glare or distracting speech).

COMBINATIONS OF ENVIRONMENTAL AND HOST STRESSORS

Although studies using a combination of environmental and host stressors have been somewhat more numerous than studies involving combinations of environmental stressors, the number is still rather limited. By far the most common have been combinations of altitude (hypoxia) with alcohol or drugs. A summary of the studies found in this review, and their major findings, is provided in Table 2.

The possible effects of altitude on persons who have taken drugs, or used alcohol, is of major concern in aviation. How altitude alone affects human performance is quite well known. Less well understood is how the effects of altitude may be increased, or possibly counteracted, by drugs or alcohol. One of the earliest and most ambitious studies, by Adler et al. (14), was concerned with the possible use of stimulating drugs to counteract the well known impairment of performance caused by hypoxia. The drugs used were several types of amphetamine, caffeine, and a combination of amphetamine and caffeine. A variety of performance tests were used, as listed in Table 2. Altitude levels were 0; 5,000; 10,000; 15,000; and 18,000 feet. Most of the drugs counteracted, to some extent, the effect of altitude on performance. There was also some evidence of a stimulating effect and improvement of performance under ground level conditions.

Another study, by Hartman and Crump (15), used acetazoiamide, a drug believed to aid in oxygen utilization. They made a 6-hour test at 14,000 feet, a 4-hour test at 16,000 feet, and a 5-day test at 14,000 feet, using quite a battery of psychomotor and paper and pencil tests. They found no reliable evidence of any effect of the drug on performance.

TABLE 2

Summary of Research Findings for Combinations of Environmental and Host Stressors

Stressors	*Authors*	*Stress Conditions*	*Performance Measures*	*Interaction Category**	*Remarks*
Altitude (Hypoxia) and Drugs	Adler et al. (14)	Altitude up to 18,000 ft.; several stimulating drugs	1-D Pursuit Tracking, Choice Reaction Time, Tapping, Letter Cancellation	4	Stimulating drugs tended to counteract impairment of performance caused by altitude.
	Hartman & Crump (15)	Altitude up to 16,000 ft.; acetazolamide	1-D Comp. Tracking, Simple Reaction Time, Hand Steadiness, and Four Paper and Pencil Tests	1	Decrement caused by altitude on some tests. No consistent effects from drug.
	Higgins et al. (16)	Altitude up to 14,000 ft.: two antihistamine drugs	Complex Coordinator	1 & 3 (?)	One drug caused no decrement. Combination of chlorpheniramine and altitude caused effect which authors claimed to be synergistic.
	Pearson & Neal (18)	Altitude up to 12,000 ft.; tranquilizer drugs, and alcohol	2-D Comp. Tracking, Visual Monitoring, Choice Reaction Time, Vigilance, Problem Solving	—	Essentially no significant effects on performance.
	Figarola & Billings (17)	Altitude to 17,000 ft.; meprobamate	2-D Comp. Tracking, Code Problem Solving, Auditory Vigilance	1 & 2	For tracking both altitude and drug caused decrement and effect of combination was additive. On other two tests effects were somewhat inconsistent.
Altitude (Hypoxia) and Alcohol	Newman (19)	Altitude to 18,000 ft.; alcohol	2-D Comp. Tracking	1 or 2	Combination of alcohol and altitude greater than alcohol alone. No data for altitude only.
	Pearson (20)	Altitude to 12,000 ft.; alcohol	2-D Comp. Tracking, Visual Monitoring, Reaction Time, Mental Arithmetic	2	Generally, decrements were small and not statistically significant for either single or combined stress.

continued on page 8

TABLE 2 (continued)

Stressors	*Authors*	*Stress Conditions*	*Performance Measures*	*Interaction Category**	*Remarks*
Noise & Sleep Loss	Corcoran (21)	Noise up to 90 dB; 57 hr. sleep deprivation	Auditory Vigilance, Serial Reaction	2 & 4	On auditory vigilance test combination of noise and sleep loss caused greatest decrement. On serial reaction test noise appeared to counteract effects of sleep loss.
	Wilkinson (22)	Noise up to 100 dB; 32 hr. sleep deprivation	Serial Reaction	4	Greatest decrement for sleep loss and quiet condition indicating that noise tended to counteract sleep loss.
Heat & Sleep Loss	Pepler (23)	Heat up to 100°F; one night sleep loss	1-D Pursuit Tracking, Serial Reaction	2	Combination of sleep loss and heat resulted in poorest performance on both tests.

*For explanation of categories see text.

Three studies have used combinations of altitude with depressant types of drugs. Higgins et al. (16) measured performance with the well known Mashburn Complex Coordinator, and used two antihistamines. Altitude levels were 0; 10,000; and 14,000 feet. One of these drugs, phenindamine, caused no significant effects on performance. The other drug, chlorpheniramine, in combination with altitude, caused a performance decrement that the authors considered as greater than an additive effect. In this reviewer's opinion, however, the data show no more than an additive effect. Figarola and Billings (17) used altitude of 3,000; 8,000; and 17,000 feet, and meprobamate. Performance on a 2-dimensional tracking task showed significant decrements for both altitude and drug effects singly. A still greater (additive) decrement occurred for the combination of altitude and the drug. The additive effect can be seen clearly in Figure 3. Figarola and Billings also used a code test, that showed a consistent decrement for the drug, but not for altitude. An auditory vigilance test showed a decrement for altitude, but not for the drug. Another study, using depressant drugs, by Pearson and Neal (18), used altitude, two tranquilizers (meprobamate and Librium) and alcohol, making a three-way combination. The altitude levels were zero and 12,000 feet, and performance was measured with a battery of tests as listed in Table 2. In spite of the simultaneous combination of three stressors, the study found essentially no significant decrements from normal performance. The authors attributed the lack of significant performance decrements in part to the moderate drug and alcohol dosages used. These dosages had been chosen so as to be fairly typical of the condition of some drivers of automobiles and operators of aircraft.

Two other studies involving combinations of altitude and alcohol were conducted by Newman (19) and Pearson (20). Newman simulated an altitude of 18,000 feet through

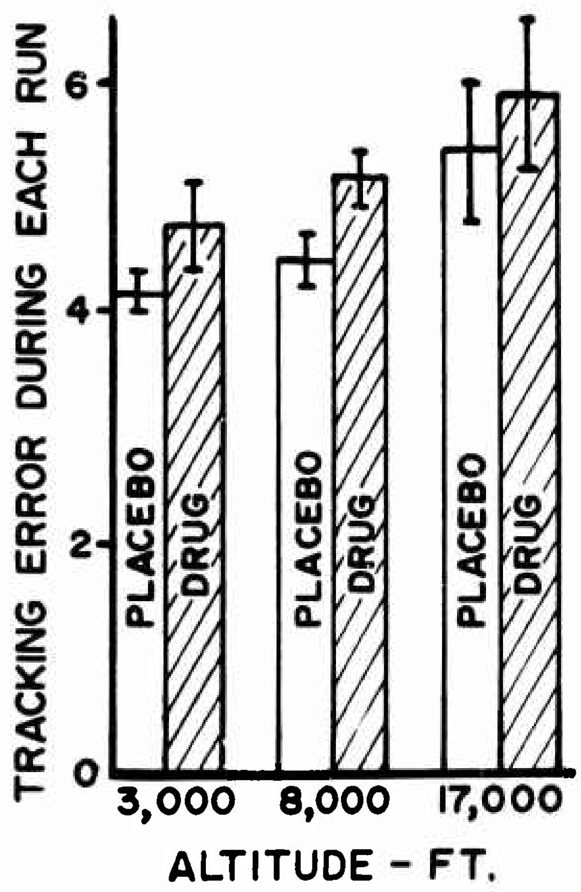

Figure 3. Effect of combined altitude and a tranquilizer drug (meprobamate) on tracking error [data from Figarola and Billings (17)]

reduction of oxygen in the breathing air, and used 2-dimensional compensatory tracking as a measure of performance. Alcohol doses were administered at 30 minute intervals until performance fell 5% below pre-exposure performance, at which time the experiment was terminated. Newman found that the deterioration of performance was more rapid for the hypoxia-alcohol combination than for alcohol alone. There was no comparison test for hypoxia only. The study by Pearson (20) closley resembled the study by Pearson and Neal (18), except that only altitude and alcohol were combined. Altitude was either ground level or 12,000 feet. A 2-dimensional tracking test showed a decrement at altitude, and some added decrement when altitude and alcohol were combined. But these decrements were not statistically significant. Other tests failed to show any consistent or significant effects of the stressors.

An interesting stress combination of noise and sleep loss has been the subject of two studies by Corcoran (21) and Wilkinson (22). The essential features of both studies are fairly well covered in Table 2. On both common sense and theoretical grounds it would be expected that noise would have an arousing or awakening effect that could counteract the decrements in performance caused by sleep loss. Both experiments found such an antagonistic effect for a serial reaction task. This is illustrated by the data of Figure 4, showing some of the data from Wilkinson's (22) experiment. On an auditory vigilance task, however, Corcoran found no such effect. In fact, on the auditory vigilance test, the poorest performance, an additive effect, occurred for the combination of sleep loss and noise.

A study by Pepler (23) combined sleep loss and heat. The high temperature condition was 100°F (dry bulb) and 90°F (wet bulb). Subjects were tested during the morning following loss of sleep the previous night. On both a 1-dimensional pursuit tracking and a serial reaction test the subjects showed performance decrements from both stresses experienced singly. Poorest performance, an additive effect, occurred when the heat and sleep loss were combined. Pepler's (23) results for the serial reaction test are shown in Figure 5. These results, when contrasted with those of Wilkinson in Figure 4 for the same test, provide a clear example of how the nature of the stresses can cause either an additive or an antagonistic effect when stresses are combined.

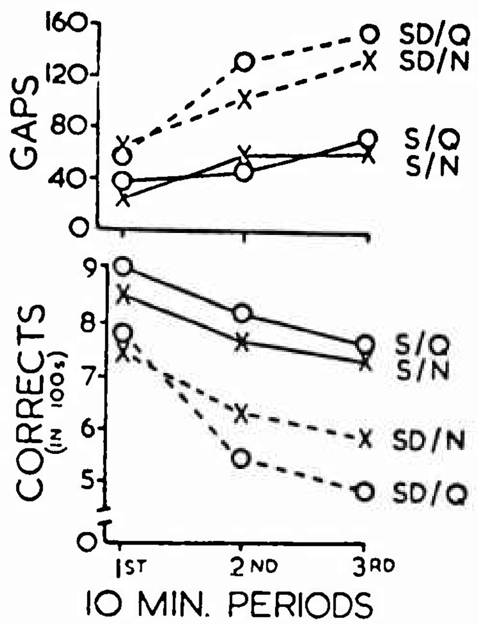

Figure 4. Effect of combined sleep deprivation and noise on performance on a serial reaction test [data from Wilkinson (22)]

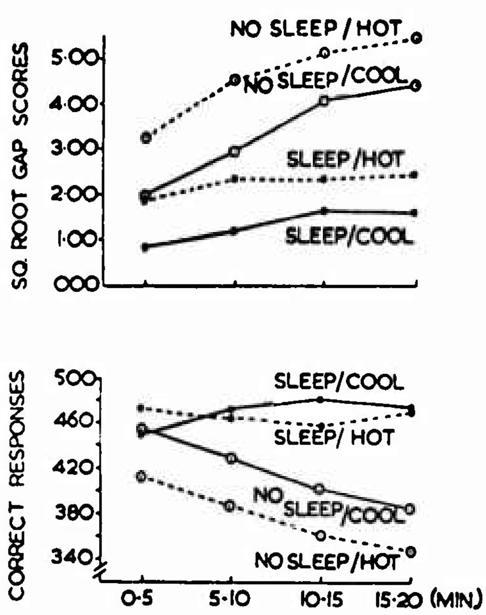

Figure 5. Effect of combined sleep deprivation and heat on performance on a serial reaction test [data from Pepler (23)]

DISCUSSION

It is clear from this review that experiments on the effects of combined stress on human performance can and do yield quite a variety of outcomes. In a fair number of experiments the results were essentially negative (Dean et al. (4 & 7); Sommer and Harris (9); Pearson and Neal (18); Hartman and Crump (15)), showing no significant or consistent decrements in performance from some of the stresses, either singly or in combination. Such negative findings must be interpreted with caution, and usually do not justify a conclusion that the stresses had no effect. Negative results are more likely to be an indication of large subject variability, insufficient numbers of subjects, low sensitivity of the performance tests, or other limitations of the experiment.

Where several performance tests were used it was common to find that different tests gave quite different results, ranging from negative findings to additive interactions for a combination of stresses (Viteles and Smith (3); Harris and Shoenberger (8); Figarola and Billings (17); Corcoran (21)). This demonstrates that performance tests differ widely in their sensitivity to specific stresses. A test that is sensitive to one type of stress may be quite insensitive to another. As has been very well pointed out by Broadbent (1), different stressors operate through different physiological or behavioral mechanisms, and thus will affect performance, and performance test scores, in correspondingly different ways. An all-purpose stress-sensitive performance test would be highly desirable, but probably does not exist.

Of special interest in this review were the types of performance interactions shown by the results of combined stress studies. The evidence concerning interactions varied rather widely, and for some studies it was not possible to assign a classification into one of the four basic types of interactions. For several studies there appeared to be at least two types of interaction depending upon which of the performance tests was being looked at. From a glance at Tables 1 and 2 it appears that the most common types of stress interaction are categories 1 and 2, that is, no interaction or an additive interaction. There are, however, several rather clear instances of category 4, antagonistic interaction. This shows up in the study by Adler et al. (14) for altitude and stimulating drugs. To consider a stimulating drug as a stress might be open to question of course. A perhaps more legitimate type of antagonistic interaction showed up for sleep loss and noise in the studies of Corcoran (21) and Wilkinson (22). On both common sense and theoretical grounds the existence of antagonistic stress interactions seems reasonable, considering the widely differing mechanisms that may be operating.

In this review no studies were found that clearly indicated a synergistic interaction for combined stresses. There was one report, by Higgins et al. (16), in which the authors claimed that the combined effect (of altitude and an antihistamine drug) was greater than additive for performance on a complex coordination (Mashburn) test. But this interpretation of their data seems open to question. Evaluating their data in the same manner as the data of other studies included in this review, I would classify their result as an additive interaction. The failure, in this review, to find any clear-cut instances of synergistic interactions for combined stresses is in basic agreement with a literature review by Murray and McCally (2). Their review was considerably broader, including in addition animal and purely physiological studies of combined stress. They found very few results they could assign to the synergistic category.

Although this review uncovered no clear case of a combined stress effect on performance that was greater than additive (i.e. synergistic), this does not justify a conclusion that such effects will not be found in future research using other stress combinations and other measures of performance. Nevertheless, we can conclude that synergistic interactions are probably uncommon and unlikely results of combined environmental stresses. On the basis of present knowledge, therefore, it would seem that in extrapolating to combined stress situations, as they occur in flight, we are fairly safe in using laboratory data from single stress studies. Furthermore, in making such extrapolations, it would seem safe to assume that combined stress effects will be no greater than additive. Such a conclusion, however, can be only tentative, and must await considerably more laboratory experimentation with combined stresses.

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